

Full Spectrum Color Detecting Pixel Camera



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5**Cross Reference to Related Applications**

The present application claims priority from provisional application 60/454,555, filed 14-Mar-03. This related application is hereby incorporated herein by reference.

Technical Field and Background Art10

This invention relates to a method of capturing full spectrum color images in an electronic color camera using a Full-Spectrum Pixel Sensor Color Analyzer.

Prior art15

The human vision system has evolved based on an environment for processing information that exists only in nature under continuous full spectrum ambient lighting conditions. Relatively recently, during the past 400 years, we have exposed our vision systems to unusual new requirements. The reading of printed text and pictures in artificial light, and screened photographs, television and computer displays having colors restricted fundamentally to three to five color primaries.

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Most film, video, digital cameras and display systems are based upon the three-color, metamerism theory of spectral capture, using Red Green Blue (RGB) or Cyan Magenta Yellow (CMY) primaries. Hence, the camera's spectral range or gamut is limited by the selected color primaries supported by the sensors and camera system. The color gamut following these tri-stimulus parameters does not

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match the enormous spectral range of the human visual system. There is no way such conventional systems can replicate what a human can see in the field, where the human visual system is capable of a color palette which cannot be physically displayed by only three to five primary lights. Furthermore, these systems are

5 inflexible, based on a mythical "standard" human observer, and cannot be readily adjusted for human diversity or handicaps. Four or five primaries are sometimes used for ink on paper or special displays, which expands the gamut somewhat, but still cannot reproduce all of the colors that humans can see.

Summary of the Invention

10 This invention comprises the means for the capture of full spectrum images in an electronic camera without the use of color primary filters to limit the spectral color gamut of the captured image. The fundamental principle of the invention is that each pixel of the image sensor acts as an independent spectrophotometer and spectrum analyzer..

Brief Description of the Drawings

The foregoing features of the invention will be more readily understood by reference to the following detailed description, taken with reference to the accompanying drawings, in which:

- 20 **Fig. 1** is the color detecting pixel element
 Fig. 2 is the photo sensitive array
 Fig. 3 is the proof of principle system design

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Detailed Description of Specific Embodiments

Definitions. As used in this description and the accompanying claims, the following terms shall have the meanings indicated, unless the context otherwise requires:

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Spectrophotometer includes any device that resolves the various regions of electromagnetic light spectrum into discrete components, through the mechanism of dispersion, and measures the radiance of these discrete components.

10 Diffraction grating spectrophotometer is a device that uses a diffraction grating as its dispersive mechanism.

15 Spectrum analyzer is an instrument that measures the irradiance energy distribution with frequency for electromagnetic waveforms, capturing their relative spacing and amplitudes over a designated bandwidth.

This invention comprises the means for the capture of full spectrum images in an electronic camera without the use of color primary filters to limit the spectral color gamut of the captured image. The fundamental principle of the invention is that each
20 pixel of the image sensor acts as an independent spectrophotometer, spectral region separator, and spectrum analyzer. By using a diffraction grating to disperse the spectrum, this invention, compared to a spectrum dispersed by a prism, yields:

- a) greater resolving power, and
- b) programmable bandpass separation and spectral distribution.

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Referring to **FIG. 1** which illustrates a preferred embodiment of the invention, electromagnetic light energy **11** from each picture element of a scene is focused by lens **12** through slit **13** onto diffraction grating **14**. The electromagnetic energy is diffracted by grating **14** into component spectral wavelengths **15**. Grating **14** acts as
30 a conventional electromagnetic frequency analyzer, dispersing the components of

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spectrum **15** at different angles based on the wavelength of each energy segment. The individual segments **15** of the spectrum are detected by electrical photosensitive line array element **16**, such as a Pixim Dyna 2000 CMOS array. Individual photodetector line array elements **17** in line array **16** that are activated by the components of dispersed spectrum **15** detect and transmit the irradiance and saturation **18** of the specific spectral region for each picture element. The sum **19** of individual detector element **17** and irradiance **18** in line array **16** determines the spectral energy function signature for each picture element.

10 In a second embodiment of the invention, the photodetector line array **16** may be constructed out of any electrically photosensitive device capable of being segmented, such as a CCD photodiode.

Referring to **Fig 2**, line array **16'** from Fig. 1 is exploded to indicate the dispersed spectral regions for wavelengths **22** from infrared to ultraviolet. The line of numbers **21** indicates 256 photodiode elements in line array **16'**. The photodiode element number 1 on array **16'** is at the infrared end of the dispersed spectrum and the photodiode element number 256 is at the ultraviolet end of the dispersed spectrum. The conventionally recognized spectrum light regions **22** — red, orange, yellow, green, blue and violet — are in between the extremes of infrared and ultraviolet light. The amplitude of detected energy at each element **21** is equivalent to the radiance at that specific wavelength, bounded by the band limitations of its spectral separation. In this embodiment, using an Ocean Optics S2000 spectrophotometer with a grating number 3, 256 photodiodes cover a total spectral bandwidth of 500 nanometers, sensitive to the electromagnetic spectrum from 350 nanometers on the ultraviolet end to 850 nanometers on the infrared end. This embodiment has a spectral region bandwidth of approximately 1.95 nanometers for each of the 256 photodiodes. If a specific photodiode element **21** in photo diode line array **16'** is active at a selected wavelength, for example red at 650 nanometers, then there is energy received at that wavelength representing a peak centered at 650 nanometers with a bandwidth equal to 1.95 nanometers.

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Referring to **Fig. 3**, which illustrates how someone experienced in the art could construct a proof-of-principle full-spectrum color prototype using contemporary and available components, light enters lens **30** and focuses the image onto collimated
5 fiber bundle **31**. Fiber bundle **31** contains n individual fibers **32**, where n is a number sufficiently large to create an image for the proof of principle. Individual fibers **32** from bundle **31** are directed to **33** through **33'** comprising n line array diffraction grating spectrophotometers **34**, such as an Ocean Optics S2000. Each individual collimated fiber **32** is directed to one of n individual line array diffraction grating
10 spectrophotometers **34** to analyze the spectral energy function signature of each pixel of the captured image. The output of each spectrophotometer **33...33'** is directed to sequential switcher **35** that selects and transmits the relevant radiance data from each pixel spectrophotometer's spectral region to switcher **35** output **36**. Output **36** is connected to computer **37** for processing and analysis of the spectral
15 energy function signature data received from each of the n spectrophotometers **34**. Computer **37** compiles and sums the spectral radiance information from each pixel and analyzes the spectral energy function signature for each pixel of the image.

To create a two-dimensional image, the array **34** of spectrometers are scanned
20 using switcher **35**, pixel by pixel, line by line for a full frame. Frames are sequenced to capture full-spectrum motion images.